Appendix A
Literature Review - Septic System Performance Criteria, Technologies, and Cost Factors

Appendix A - Literature Review—Septic System Performance Criteria, Technologies, and Cost Factors

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DATE: July 12, 2006

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Introduction

As part of Anne Arundel County's plan to implement its part of the Chesapeake Bay Watershed Restoration Fund, CH2M HILL is conducting a septic system evaluation study to identify and prioritize projects to address nutrient loads associated with septic systems countywide. Task 1 of the study involves identifying, categorizing, and prioritizing septic systems. Future tasks include a preliminary cost analysis of onsite septic system upgrades and cluster community wastewater systems, preliminary cost analysis of sewer system extensions, and an implementation plan and final report. The purpose of this literature review is to identify potential evaluation criteria used in other similar programs.

Summary

Fourteen evaluation criteria were divided into four groups: pollutant removal performance, siting and design, environmental considerations, and cost. Key points gleaned from this literature review are summarized for each group below. Note that the criteria described below reflect those identified as typical standards in the literature, but should not be construed as recommended values for Anne Arundel County.

Pollutant Removal Performance for Conventional and Innovative Onsite Systems

- **Nitrogen Removal**
  - Ammonia to nitrate conversion rates for conventional system drainfields typically range from 85 percent to 95 percent
  - Total nitrogen removal typically ranges from 10 percent to 20 percent for conventional systems.
  - Shallow drainfields can remove as much as 43 percent total nitrogen.
  - Recirculating sand filters can reduce nitrogen by 36 percent to 56 percent.
  - Other recirculating systems can remove 45 percent to 76 percent total nitrogen.
- **Fecal Coliform Removal**
  - Conventional treatment systems remove 99.9 percent of bacteria.
  - Innovative onsite systems remove 96.7 percent to 99.8 percent of bacteria.

Siting and Design for Conventional and Innovative Onsite Systems

- **Allowed Housing Density**
  - Minimum lot size of 15,000 sq ft if served by public water.
  - Minimum lot size of 20,000 sq ft if served by private well.
  - Minimum 10,000 sq ft needed for onsite treatment system, exclusive of buildings, driveway, etc.
- **Soil Percolation Rates**
  - Traditional onsite systems—1 to 30 min/in.
  - Alternative onsite systems—30 to 60 min/in.
  - Mound systems—60 to 120 min/in.
- **Depth to Groundwater**
  - Minimum 4-foot separation between the bottom of the onsite system drainfield and the top of the groundwater.
  - Never less than 2-foot separation from the natural ground surface to the top of the water table.

- **Ground Slope**
  - Less than 25 percent.

Environmental Considerations of Onsite Systems

- **Proximity to Surface Water**
  - Minimum 25-foot separation to drainage ways and gullies.
  - Minimum 100-foot separation to water bodies not serving as potable water supplies.
- **Proximity of Drainfields to Potable Water Sources**
  - Minimum 100-foot separation from any water well system in an unconfined aquifer.
  - Minimum 50-foot separation from any water well system in a confined aquifer.

Cost for Innovative Onsite Systems

Most innovative systems will cost between $8,000 and $20,000 per connection based on 2002 dollars (see Table 2 for different treatment option costs). Cluster systems costs between $8,000 and $15,000 per connection for new construction and between $12,000 and $25,000+ for existing development (2004 dollars). Conventional systems cost between $3,000 and $6,000 based on 2002 dollars.

Background

The purpose of this literature review was to research various evaluation criteria that are proposed to be used in evaluating Anne Arundel County's options in managing pollutants from existing onsite sewage treatment systems. Twenty one sources were reviewed. References ranged from policy statements to design manuals to local and state regulations.

Several references (Halvorsen et al., 2004; U.S. EPA et al, 2005; and U.S. EPA, 2005) are strong policy statements with little or no engineering or planning value. Others dealt with management of onsite systems from an organizational and procedural standpoint, with little discussion of engineering and planning (U.S. EPA, 2003, and National Decentralized Water Resources Capacity Development Project, 2002).

The Cluster Wastewater Systems Handbook (Lombardo, 2004) is a good planning tool for small municipalities trying to determine the best sewage treatment option for a new subdivision. It provides a good framework for such planning, providing process flow charts to aid in data collection, assessment, and decision making. Unfortunately, it lacks hard data to assist in making a decision. Its main focus for new development is to assess whether there is adequate capacity onsite to build the cluster system.

Evaluation Criteria

Fourteen evaluation criteria were researched over the course of the literature review. The evaluation criteria were divided into four groups: pollutant removal performance, siting and design, environmental considerations, and cost. Brief descriptions of each evaluation criteria are provided below.

Pollutant Removal Performance for Conventional and Innovative Onsite Systems

- **Nitrogen Removal**. The main driver for finding alternatives to traditional onsite sewage treatment is the reduction of nitrogen discharging to the Chesapeake Bay and its tributaries.

- **Fecal Coliform Removal**. The County is anticipating that MDE will issue TMDLs for fecal coliform. A potential source of fecal coliform is substandard septic systems.

Siting and Design for Conventional and Innovative Onsite Systems

- **Density of Onsite Systems.** The number of onsite systems within a certain area. This can also be expressed as the minimum separation distance between systems.

- **Allowed Housing Density**. Allowed housing density is similar to density of septic systems. The minimum lot size or number of houses per unit area that still allows onsite treatment.

- **Soil Percolation Rates**. This is the rate at which water is conveyed through the soil matrix. It is also described as the soil hydraulic conductivity under saturated conditions. It is typically expressed as either min/in or in/hr.

- **Depth to Groundwater**. The distance separating the bottom drain field section of the onsite system from the top of the seasonally high groundwater level for the site.

- **Ground Slope**. The acceptable range of vertical rise or fall over horizontal distance. It is usually expressed as percent grade.

- **Proximity to Existing Sewer Service**. The distance to existing sewer service may preclude the use of onsite systems.

- **Proximity to Planned Sewer Service**. The distance to planned sewer service may preclude the use of onsite systems or acknowledge the temporary nature of the onsite system.

- **Topography Relative to Existing Sewers**. Onsite systems that are located down slope from existing sewers will be more expensive to connect to the sewer than those onsite systems located up slope.

Environmental Considerations of Onsite Systems

- **Known Areas of Onsite System Failure**. Septic failure is usually due to either poor site conditions, poor maintenance, or both.
- **Proximity to Surface Water**. This is the distance to any surface water.
- **Proximity of Drainfields to Potable Water Sources**. This includes minimum distances to both surface supply and wells.

Cost for Innovative Onsite Systems

- **Cost**. Future tasks will require a method of determining cost for different options.

Pollutant Removal Performance for Conventional and Innovative Onsite Systems

The literature review focused on two pollutants of concern—total nitrogen and fecal coliforms. Part of Maryland' Chesapeake Bay Restoration Fund requires Anne Arundel County to reduce the nitrogen discharged to the Chesapeake Bay and its tributaries from onsite systems. Many of the County's waters are currently listed as impaired because of either high fecal coliform or *e. coli* concentrations.

Innovative or alternative onsite systems are those systems that go beyond a conventional onsite system comprised of septic tank and drainfield. Innovative onsite systems can be used to achieve effluent water quality goals that are not possible with conventional systems. Innovative onsite systems include: single-pass and recirculating media filters, aerobic treatment units, drip distribution systems, treatment wetlands, and peat filters.

Nitrogen Removal

According to one source (Joubert et al., 2003) domestic septic tank effluent has an average nitrogen concentration of 40 mg/L with an observed range of 40 to 100 mg/L. It is not clear whether this is total nitrogen (TN), total Kjeldhal nitrogen (TKN), or ammonia as nitrogen (NH4). It is assumed for this discussion that nitrogen refers to TN unless otherwise noted. Another source (U.S. EPA, 2002) lists the characteristics of domestic septic tank effluent for five different studies. Ranges for TKN were 39 to 82 mg/L. The same reference also summarizes septic tank effluent concentrations for five small community and cluster systems. The range for TN was 29.5 to 63.4 mg/L. Flows associated with the TN concentrations were 36 to 60 gpcd.

Conventional Onsite Systems

Conventional onsite systems are very good at converting ammonia to nitrate (nitrification). Typical ammonia to nitrate conversion rates are listed as 85 percent to 95 percent. However, most of the nitrate associated with the discharge from a conventional drainfield does not undergo denitrification. Typically total nitrogen is reduced by 10 percent to 20 percent by conventional onsite systems (Joubert et al., 2003). Many sources, including Lombardo (2004), caution against assuming that subsurface systems remove any nitrogen without scientific proof such as site specific data.

Innovative Onsite Systems

In many cases, innovative onsite systems include denitrification as a design goal. They include design elements such as recirculation and aerobic treatment zones to achieve higher rates of nitrogen removal. Shallow drainfields can achieve as much as 43 percent nitrogen removal. Recirculating sand filters (RSFs) are shown by a number of studies to remove between 36 percent and 56 percent total nitrogen (Christopherson et al., 2000, and Gustafson et al., 2000c). Other sources suggest site nitrogen removal ranges of 45 percent to 76 percent for recirculating systems and 10 percent to 47 percent for single pass filters (U.S. EPA, 2002).

Fecal Coliform Removal

According to one source (Joubert et al., 2003) domestic septic tank effluent has a pathogen (bacteria and viruses) concentration of 10^6–10^8 mg/L. This may actually be 10^6–10^8 MPN/100 mL because pathogen concentrations are rarely expressed as mg/L.

Conventional systems can remove most pathogens with removal rates of 99 percent–99.99 percent (U.S. EPA, 2002). Single pass innovative systems have similar removals (99 percent–99.98 percent) while recirculating filters have slightly lower but still excellent removal rates (96.7 percent– 99.6 percent).

Siting and Design of Conventional and Innovative Onsite Systems

Density of Onsite Systems

Several sources cautioned against the placement of too many onsite systems in too small of an area. However, most sources stated that local conditions would dictate the density of onsite systems.

Allowed Housing Density

The Code of Maryland regulations require a minimum of 10,000 sq ft (not including buildings or other structures) of any lot for the construction of a new onsite system (COMAR 26.04.02.04). Anne Arundel code requires a minimum lot size of 15,000 sq ft if the property is not served by a private well and 20,000 sq ft if the property is served by a private well. One other source (Christopherson and Gustafson, 2006) divides cluster systems into the following categories based on housing density:

- Individual - < 6 dwellings or < 2,500 gpd
- Mid-sized – 6–30 dwellings or 2,500–10,000 gpd
- Large - > 30 dwellings or > 10,000 gpd

Anne Arundel County typically uses 250 gpd for one equivalent dwelling unit (EDU). Table 1 is copied from the Cluster Wastewater Systems Planning Handbook (Lombardo, 2004) to show the different treatment options available for different design flows. Less than 2,000 gpd is the equivalent of less than 8 EDU, 2,000–10,000 gpd is the equivalent to 8–40 EDU, 10,000–20,000 gpd is the equivalent to 40–80 EDU, and 20,000–50,000+gpd is the equivalent to 80-200+ EDU.

Soil Percolation Rates

Anne Arundel code (Anne Arundel County) requires the following soil percolation considerations:

- Traditional onsite—1 to 30 minutes/inch or 2 to 60 inches/hour
- Alternative onsite—30 to 60 minutes/inch or 1 to 2 inches/hour
- Mounds—60 to 120 minutes/inch or 0.5 to1 inches/hour.

These values are consistent with both Maryland regulations (COMAR 26.04.02.04) and U.S. EPA design guidance (U.S. EPA, 1980).

Depth to Groundwater

The literature discusses the distance to the water table in two different ways. The first, depth to groundwater, is the minimum from the ground surface to the water table. According to most sources, the preference is that this distance is a minimum of 4 to 5 feet. Several sources prohibit constructing an onsite system where the depth to groundwater is less than 2 feet.

TABLE 1
Wastewater Treatment Technology Options (Lombardo, 2004)

Table 5-1
Wastewater Treatment Technology Options

Pretreatment Needed	Technology+	Design Flows (gpd)			
		<2,000	2,000–10,000	10,000–20,000	20,000–50,000+
	Pretreatment				
	Septic Tank++	✓	✓	✓	✓
✓	Anaerobic Upflow Filter	✓	✓	✓	✓
	Secondary Treatment				
	Fixed Film Growth				
	Rotating Biological Contactor		✓	✓	✓
	Trickling Filter +++	✓	✓	✓	✓
✓	Subsuface Wetlands—Vegetated Submerged Beds	✓	✓	✓	✓
✓	Constructed Wetlands (FWS)			✓	✓
✓	Recirculating Media Filters	✓	✓	✓	✓
✓	Intermittent Media Filters	✓	✓	✓	
	Suspended Film Growth				
	Oxidation Ditch				✓
	Activated Sludge Systems	✓	✓	✓	✓
	Sequencing Batch Reactor	✓	✓	✓	✓
	Membrane Bioreactor			✓	✓
	Integrated Fixed Film-Suspended Growth	✓	✓	✓	✓
	Advanced Treatment				
✓	Nitrogen Removal	✓	✓	✓	✓
✓	Phosphorus Removal	✓	✓	✓	✓

Notes:
+ Depending on method of dispersal, disinfection systems may or may not be required.
++ Tank may be part of collection system or located at treatment site.
+++ Various media, usually with recirculation.

The second, and more important factor, is the separation between the bottom of the onsite system drainfield and the top of the water table. Anne Arundel County code requires a 4-foot separation, which is consistent with both Maryland Code (COMAR 26.04.02.04) and U.S. EPA design guidance (U.S. EPA, 1980, and U.S. EPA, 2002). Mound systems are allowed where there the depth to groundwater is 2 feet. However, these systems are generally required to establish the 4-foot separation through construction of the mound.

Ground Slope

Steep ground slopes impact an onsite system's treatment capacity. Maryland regulations require slopes less than 25 percent (COMAR 26.04.02.04). Other sources have similar requirements. U.S. EPA guidance has moved from less than 25 percent slope for a conventional system (U.S. EPA, 1980) to less than 20 percent slope and definitely avoid greater than 30 percent slope in its most recent design guidance (U.S. EPA, 2002). Ground slope should never be confused with the slope of a treatment trench in a conventional drainfield. Most sources emphasize are drainfield that is level to nearly level (4-inch change in elevation over 100 feet of length).

Environmental Considerations of Onsite Systems

Known Areas of Onsite System Failure

Maryland has an estimated failure rate of 1 percent (U.S. EPA, 2002).

Proximity to Surface Water

Maryland regulations require a minimum separation of 25 feet to drainage ways and gullies and a minimum separation of 100 feet to water bodies not serving as potable water supplies (COMAR 26.04.02.04). Other sources discuss 50–100 feet minimum separation distances (U.S. EPA, 1980).

GWLF modeling for New York City's reservoir watersheds west of the Hudson River assumed that nutrients from septic systems would not significantly reach a stream if there were more than 300 feet of separation (City of New York, 2001). The 300-foot figure is not substantiated in the reference. It is also not clear if the 300-foot distance is based on nitrogen or the more easily removed phosphorus. Phosphorus is typically the limiting nutrient in lakes and reservoirs and is, presumably, the focus of New York City's GWLF modeling efforts.

State of Maryland Chesapeake Bay critical areas extend inland 1,000 feet from the edge of tidal rivers.

Proximity of Drainfields to Potable Water Sources

Anne Arundel code has a 100-foot minimum separation from a drinking water well that is in an unconfined aquifer and a 50-foot minimum separation from a drinking water well that is in a confined aquifer. Maryland regulations require the following minimum separation distances of onsite systems and potable water supplies:

- 300 feet to the elevation of spillway crest level of water supply reservoir.
- 200 feet from any stream bank less than 3,000 feet upstream of a potable water intake.
- 100 feet from any stream bank greater than 3,000 feet upstream of a potable water intake.
- 100 feet from any water well system in an unconfined aquifer.
- 50 feet from any water well system in confined aquifer.

The first three requirements are of no consequence because there are no surface water intakes or reservoirs located in the County. The U.S. EPA has also recommended a 50-100 foot separation from water supply wells (U.S. EPA, 1980).

Cost for Innovative On-Site Systems

Cluster system costs are listed by one source in 2004 dollars as $8,000–$15,000 per connection for new construction and <$12,000–$25,000+ per connection for existing development (Lombardo, 2004). A cost analysis based on sewer extension costs is provided in the Attachment (Table A-1).

Table 2 summarizes the design and installation costs from the University of Minnesota Extension Service (Gustafson et al., 2002) innovative onsite sewage treatment webpage.

TABLE 2
Summary of Innovative Onsite Treatment Costs

Treatment Option	Design and Installation (2002)	Appropriateness for Individual Small Lots
Aerobic Tank	$8,000 - $12,000	Yes
Peat Filter	$8,000 - $12,000	Maybe
Single-pass Sand Filter	$8,000 - $12,000	Maybe
Recirculating Media Filter	$8,000 - $12,000	Yes
Constructed Wetland	$10,000 - $12,000	No
Trench	$3,000 - $6,000	Maybe
Mound	$5,000 - $10,000	Maybe
Drip Dispersal	$8,000 - $12,000	No
Municipal Collection	$5,000 - $10,000+	Yes

Source (Gustafson, et al, 2002)

The costs summarized in Table 2 are similar to those costs found in other sources from the University of Minnesota (Christopherson et al., 2000; Gustafson et al., 2000a, 2000b, 2000c).

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Attachment

TABLE A-1
Example of Cost Effectiveness Analysis Results For Concord (Sorted by Unit Sewer Connection Cost)

Sub-Area	Distance to Sewer Individual Study Areas (Feet)*	Sewer Connection Cost	Design Flows (Title 5 Flows) (gpd)	Unit Sewer Connection Cost ($/gpd)	Results (1)
1	100	$10,000	46,200	$0.22	Sewer
2	100	$10,000	30,030	$0.33	Sewer
3	400	$40,000	99,880	$0.40	Sewer
4	230	$23,000	23,100	$1.00	Sewer
5	100	$10,000	4,840	$2.07	Sewer
6	100	$10,000	4,290	$2.33	Sewer
7	650	$65,000	17,270	$3.76	Sewer
8	100	$10,000	1,760	$5.68	Sewer
9	900	$140,000	22,000	$6.36	Sewer
10	100	$10,000	1,430	$6.99	Sewer
11	1,850	$235,000	31,240	$7.52	Sewer
12	1,345	$134,500	16,940	$7.94	Sewer
13	800	$80,000	7,150	$11.19	FAN
14	1,800	$230,000	19,910	$11.55	FAN
15	100	$10,000	770	$12.99	FAN
16	2,800	$330,000	24,090	$13.70	FAN
17	7,500	$800,000	53,020	$15.09	FAN
18	900	$140,000	8,910	$15.71	FAN
19	1,700	$220,000	13,640	$16.13	FAN
20	7,500	$800,000	41,360	$19.34	FAN
21	1,050	$155,000	6,820	$22.73	FAN
22	8,000	$850,000	32,450	$26.19	FAN
23	12,000	$1,250,000	16,060	$77.83	Cluster
24	7,400	$740,000	8,800	$84.09	Cluster
25	5,300	$580,000	5,060	$114.62	Cluster
26	4,300	$480,000	4,180	$114.83	Cluster
27	14,000	$1,450,000	12,320	$117.69	Cluster
28	8,500	$900,000	4,070	$221.13	Cluster

TABLE A-1
Example of Cost Effectiveness Analysis Results For Concord (Sorted by Unit Sewer Connection Cost)

Sub-Area	Distance to Sewer Individual Study Areas (Feet)*	Sewer Connection Cost	Design Flows (Title 5 Flows) (gpd)	Unit Sewer Connection Cost ($/gpd)	Results (1)
29	7,500	$800,000	3,520	$227.27	Cluster
30	16,000	$1,650,000	4,730	$348.84	Cluster
31	16,000	$1,650,000	4,290	$384.62	Cluster
32	17,000	$1,750,000	2,640	$662.88	Cluster
33	11,000	$1,150,000	1,320	$871.21	Cluster

(1) Sewer option for <$10/gpd. Cluster option for >$50/gpd.
FAN – Further analysis needed
Source (Lombardo, 2004)